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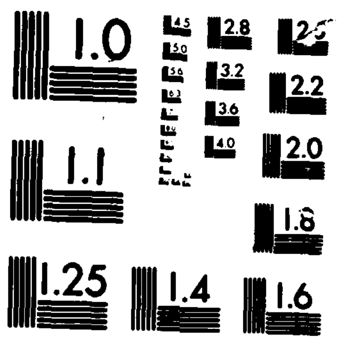

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MTL TR 86-12

BATTLEFIELD ARMOR REPAIR KITS - PART 2

ALAN J. GOLDMAN and DENNIS W. GOSSELIN
ARMOR MATERIALS DIVISION

April 1986

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US ARMY
LABORATORY COMMAND
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U.S. ARMY MATERIALS TECHNOLOGY LABORATORY
Watertown, Massachusetts 02172-0001

REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: MTL TR 86-12	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): BATTLEFIELD ARMOR REPAIR KITS - PART 2	5. TYPE OF REPORT & PERIOD COVERED: Final Report
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Alan J. Goldman and Dennis W. Gosselin	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U.S. Army Materials Technology Laboratory, Watertown, Massachusetts 02172-0001, SLCMT-MCP	10. PROGRAM ELEMENT PROJECT, TASK AREA & WORK UNIT NUMBERS: D/A Project: 1L263102D081; AMCMS Code: 623102.0810011
11. CONTROLLING OFFICE NAME AND ADDRESS: Logistics and Readiness Analysis Division, U.S. Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, Maryland 21005	12. REPORT DATE: April 1986
	13. NUMBER OF PAGES: 17
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS (of this report): Unclassified
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Submitted as a letter report to Chief, Logistics and Readiness Analysis Division, U.S. Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, Maryland 21005, November 1984.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Armor	Cement	Metallic armor
Damage	Repair kits	Body filler
Polyester resins	Methacrylates	Adhesives

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

(SEE REVERSE SIDE)

Block No. 20

ABSTRACT

A readily available, inexpensive auto body filler is useable for battlefield armor repair at temperatures between 32°F and 95°F. The filler contains 50% polyester resin and 50% magnesium silicate. It has a federal stock number and is easily procured through GSA.

A feasible but more expensive hole filler is a reinforced gypsum cement commercially known as Armor-Plug. It has the advantage of being odorless. Both products have a shelf-life of two years. Armor-Plug costs $0.34 for one application, compared with $0.22 for the auto body filler. In explosive tests performed by troops from the Fort Knox Armor School and the Aberdeen Ordnance Center and School, both of these hole fillers performed virtually the same.

CONTENTS

BACKGROUND

A report[1] on Battlefield Armor Repair Kits published in November, 1984 detailed a study of more than 40 adhesives which were used to fill the damaged area or affix a metal patch. A commercially available polyester with glass fiber reinforcement withstood .50 caliber AP projectile hits and a 1/4-lb pentolite explosive charge two inches from the periphery of the filled damage area. Furthermore, when the damaged hole was covered by armor plate mounted on three stud bolts, it was protected against a direct hit by the .50 caliber AP projectile or the 1/4-lb pentolite charge.

A commercially available fiberglass soaked with methacrylate provided protection against the weather and, when used to affix an armor patch, provided nuclear, biological, chemical, (NBC) and limited ballistic protection. Both this adhesive and the hole filler were tested at 70°F. They could not be applied below 60°F for the polyester and 50°F for the methacrylate-soaked fiberglass.

The objective of the current study was to lower the useful application temperature to 32°F. The most feasible patch materials were subjected to chemical agent tests. Other tests of interest were performed and are reported.

TEST RESULTS AND DISCUSSION

General

A number of adhesives specially designed for low temperature application and a polyester with a federal stock number were evaluated~~. Also studied were~~ along with a group of cements. Since the cements must be mixed with water, they are useful to temperatures just above the freezing point (32°F).

Lap Shear Strength

As described in Reference 1, the lap shear strength test (ASTM method D-1002) is frequently used to determine the relative shear strength of adhesives used for metal-to-metal bonding. Although the test is useful for evaluating adhesives, it cannot be used for cements which have negligible shear and tensile strengths.

A series of adhesives were evaluated at the Army Cold Region Research and Engineering Laboratory (CRREL), Hanover, NH. The adhesives were stored overnight at 32°F and the lap shear tests were performed in a special chamber which was also cooled to 32°F. The results are given in Table 1.

Small quantities of the adhesives were placed in a 0°F freezer overnight. They were all too hard to use. In addition, as noted under Table 1, the two Dynatron Bondo epoxies were unstable in storage, and unuseable for a second round of testing six months after the first tests.

The two ITW adhesives and the auto body filler showed good adhesion characteristics at 32°F and were tested further, along with four cements.

1. GOLDMAN, A. J., and GOSSELIN, D. W. *Battlefield Armor Kits.* U.S. Army Materials Technology Laboratory, AMMRC Letter Report, November 1984, also U.S. Army Materials Technology Laboratory, MTL TR 85-30, October 1985.

Table 1. LOW TEMPERATURE (32°F) CURE AND LAP SHEAR STRENGTHS

Adhesive	Source	1-Hour Cure (psi)	2-Hour Cure (psi)	4-Hour Cure (psi)
Auto Body Filler*	GSA	450	710	1290
Bondo Short (≤1/32") hair†	Dynatron Bondo	233	740	-
Bondo Long (>1/2") hair†	Dynatron Bondo	6	518	-
Devcon Short (<1/32") hair†	ITW Adhesives	1034	1100	-
Devcon Long (>1/2") hair†	ITW Adhesives	2106	2326	-

*50% polyester resin, 50% magnesium silicate. Federal stock number 8010-00-926-2133.
†Two-part fiber-reinforced experimental epoxies.

The two Dynatron Bondo epoxies shown above were unstable in storage. After storing for six months at room temperature and cooling to 32°F, they were too hard for testing. The auto body filler and Devcon products could be retested at 32°F after six months storage at room temperature.

Cements

Four cements were evaluated as possible hole fillers.

1. Armor-Plug manufactured by Genstar Stone Products, Hunt Valley, MD - a glass fiber-reinforced gypsum-based cement (see Appendix A).

2. Duracal (U.S. Gypsum) Portland cement and gypsum + 25% silica + 0.2% Lomar D (Diamond Shamrock) + 2% chopped 1/4-inch fiberglass, 35 parts water to 100 parts mixture.

3. Set Plug manufactured by Master Builders, Cleveland, OH - gypsum (calcium sulfate)-based cement for plugging water leaks.

4. Set 45 manufactured by Master Builders, Cleveland, OH - magnesium phosphate-based cement for highway repair.

Impact Tests

The four cements and the auto body filler were subjected to a ~~specially designed~~ 500 ft/lb impact test ~~as described~~ in Reference 1. The auto body filler remained in place in the hole after the impact. The Armor-Plug and Duracal each lost a small amount of material. Approximately one-half of the plug broke off in the cases of Set 45 and Set Plug.

Artificial Heating Methods

Methods of heating armor from temperatures below 32°F to the preferred application temperature range, above 50°F, were explored. Two methods, the self-regulating heater (manufactured by Raychem and Metcal, both located in Menlo Park, CA), and the NASA toroid induction heater[2] were promising. A medical-chemical heating pad NSN 6530-00-786-464 was not as successful in raising the temperature of 3/4-inch-thick armor steel.

2. STEIN, B. A., TYERYER, J. R., and HODGES, W. T. *Rapid Adhesive Bonding Concepts.* NASA Technical Memorandum 86256, June 1984.

1. A self-regulating heater 3/8" x 11-3/8" x 7-1/2" was used to heat a piece of rolled homogenous armor (RHA) steel 3/4" x 12" x 12" from 15°F to 60°F in 15 minutes using a 24-volt source - the voltage available on a tank.

2. A piece of steel 1" x 4" x 4" with a 3/4-inch hole was heated from room temperature to 400°F in two minutes using a 110-volt source and the toroid induction heater available at the NASA Langley Research Center. A 24-volt source would result in a longer time to reach 400°F or to reach a lower temperature in two minutes. In any event, the feasibiltiy of heating armor steel using the NASA method was demonstrated.

If a decision is made to pursue either of these approaches, tests will have to be performed on much larger pieces of armor to more nearly duplicate the heat sink represented by the armor of a combat vehicle.

Explosive Tests

Tests at Fort Devens, MA

A 12" x 12" x 1" plate of aluminum was drilled with a 1-inch drill, and to simulate the rough condition of a ballistic penetration, the holes were threaded using a 1-1/8 inch - 7 tap. The holes were cleaned with trichlorethane and dried with compressed gas. One side was covered with aluminum tape and the holes were filled from the other side. Each plate was drilled and tapped four times, three inches from the center, and each filler was packed into diametrically opposite holes. A 1/4-lb C4 explosive charge was detonated 2-3/4 inches above the center of the plate after one-hour cure time.

The following fillers survived the C4 explosion with no damage:

- Dyna Hair
- Bondo Glass
- Bondo Short Epoxy
- Bondo Long Epoxy
- Loctite Output
- Silastic 732 RTV.

The following were brittle and chipped badly:

- Devcon Short Epoxy
- Devcon Long Epoxy.

Field Tests at Aberdeen Proving Ground, MD

First, a series of tests were run using four cements, one polyester resin, and one specially formulated low temperature epoxy. After 1 hour and 50 minutes cure time a 3/16-lb pentolite charge was exploded on the 2-inch-thick RHA plate, 6 inches from the repaired hold. The auto body filler, Armor-Plug, Duracal mixture, Set 45 with fiberglass, and Set Plug with fiberglass all showed no damage. The Devcon short epoxy had a piece blown off the backside.

Since the auto body filler and Armor-Plug are both readily available from GSA (very easily purchased) and Genstar Stone products, respectively, these two hole

fillers were selected for testing by soldiers from the Ft. Knox Armor School and the APG Ordnance School. The instructions for each filler are given in the Appendices B and C.

Repair tests were performed on an M48 tank (several holes approximately 1/2 inch in diameter resulting from firing shaped charges), 1/4-inch thick steel (typical of BFV and M1) with 1-1/2-inch to 2-inch diameter holes, 1-inch thick 5083 aluminum (typical of M113) and two 1/4-inch thick steel plates spaced 1 inch apart. All repairs were accomplished by one man in 7 to 15 minutes.

After filling the holes, half with body filler and half with Armor-Plug, 3/16-lb pentolite charges were exploded on the plates 4 inches to 6 inches from the filled hole, except in the case of spaced armor where the charge was centered 2 inches above the top of the two plates.

The results of the pentolite explosion were as follows:

	Body Filler	Armor-Plug	Cure Time
M48	no effect	no effect	3 hours
1" 5083 Al	no effect	no effect	3 hours
1/4" steel	blew out	blew out	3 hours
1/4" steel spaced	no effect	blew out	40 minutes.

The explosives directly on the 12" x 12" x 1/4"-plate were too severe a test. In fact, the plates were severely damaged. The standoff test on the 1/4-inch-spaced steel plates was more realistic.

The soldiers critiqued the body filler and Armor-Plug. There was a strong preference for the Armor-Plug because it was easier to apply and did not have any odor. The odor of the polyester body filler was more offensive indoors than out in the test area. The body filler also tended to have too much fluid which presented more difficulty in filling the holes in the 1/4-inch-thick plate. This could be alleviated by using 2 inches or 3 inches of hardener rather than 1 inch, and using a screen to partially block the hole.

Figure 1 shows the auto body filler used with a screen to fill a hole in the 1/4-inch-thick plate. The screen (either steel or plastic 16 per inch) prevented the filler from running through the hole.

Vacuum Tests

In order to determine whether the most promising patches would provide NBC and moisture protection, a bell jar was placed over the patch and an attempt was made to evacuate the bell jar (Figure 2). Successful evacuation to a pressure of 200 M torr was taken as evidence that the patch was gas tight and would provide weather and short-time NBC protection.

Both the patches filled with auto body filler and Armor-Plug were evacuated to less than 200 M torr indicating acceptable weather and short-term NBC protection. The Duracal mixture was more porous and could be evacuated to only 640 M torr. This was not satisfactory.

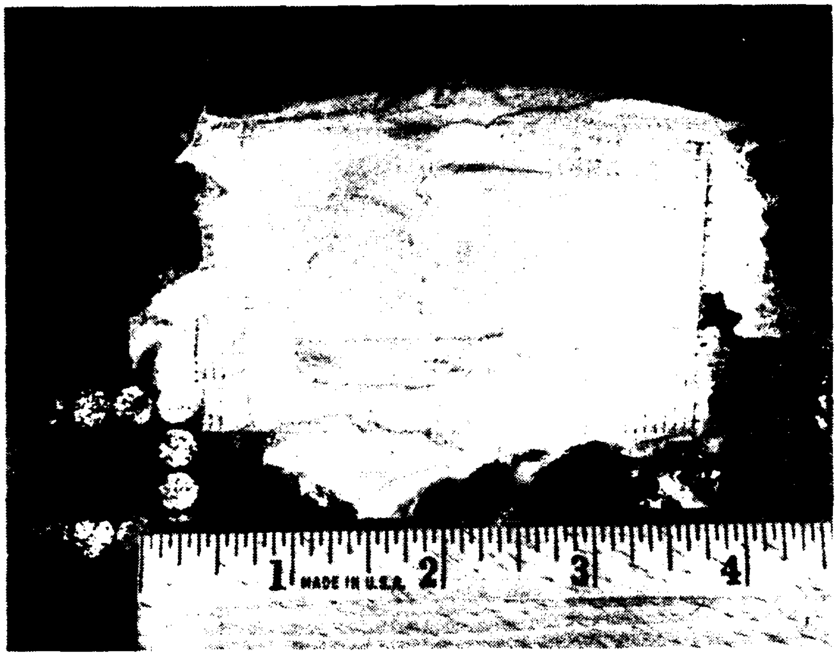

Figure 1. Auto body filler applied to hole in a 1/4" steel plate using screen to prevent runout.

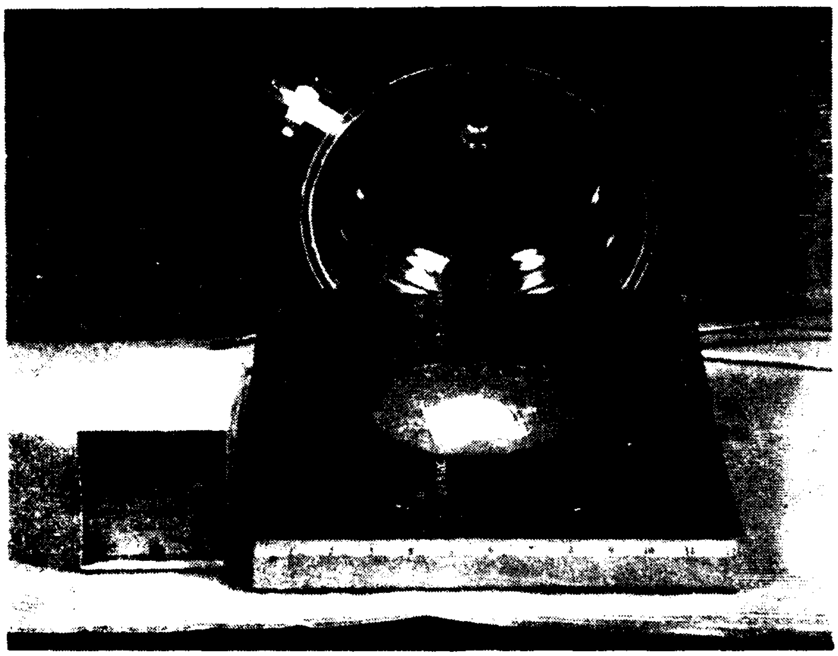

Figure 2. Assembly of bell jar over patch for evacuation test.

Chemical Agents

Both the auto body filler and Armor-Plug were subjected to chemical agent testing at Southern Research Institute, Birmingham, Alabama. One-half-inch diameter holes were drilled in 1/16-inch stainless steel plate and the holes were filled.

The first series of tests measured the permeation rates of GD nerve gas and HD mustard gas through holes filled with the auto body filler and Armor-Plug. The cumulative permeation was zero for both agents, and there was no breakthrough in 24 hours for the auto body filler. Both gases did permeate Armor-Plug - in about five hours for mustard gas, and less than one hour for nerve gas.

The second series of tests measured decontamination/desorption. Five 2-microliter drops were placed on the whole filler and the agent was allowed to soak-in for one hour. A 10% hypochlorite decontamination solution was then applied to the surface. The hypochlorite solution was then washed thoroughly and rinsed. The desorption (offgassing) of the agent was then measured. The auto body filler showed a lower desorption than the Armor-Plug using both agents. This means that less of the agents were adsorbed in the auto body filler. Some agent, however, was adsorbed by the auto body filler.

The researchers at Southern Research Institute concluded that although neither hole filler is completely resistant to chemical agents, the auto body filler is significantly more resistant than the Armor-Plug.

ECONOMIC ANALYSIS

The following table lists the cost of materials of applying various patch systems.

	Cost/Repair
Auto body filler	$ 0.22
Armor-Plug	0.34
Fiberglass-reinforced polyester (Ref. 1)	0.29
Methacrylate-soaked fiberglass (Box Patch) (Ref. 1).	15.00

The auto body filler, a polyester resin, and the fiberglass-reinforced polyester have an economic advantage over the other alternatives.

Costs of the body filler, Armor-Plug, and reinforced polyester are for a quart can containing sufficient material for ten patches.

NOTE: Using Box Patch for repair of leaks - Box Patch was used successfully at Ft. Knox to repair a leaking oil pan on a crane and a leak on a M60 fuel tank. These specialized applications may justify the more costly repair.

CONCLUSIONS

1. An inexpensive, easily procured, auto body filler, containing 50% polyester resin and 50% magnesium silicate is useful for repairing armor damage in steel and aluminum.

2. Another viable but more expensive hole filler is a gypsum-based reinforced cement called Armor-Plug.

3. Both hole fillers have been demonstrated by troops on steel and aluminum armor and can withstand the shock of a 3/16-lb pentolite explosion 4 inches from the damaged area.

4. The soldiers preferred Armor-Plug because it is easier to apply and is odorless.

5. The auto body filler is less expensive than the cement, \$0.22 versus \$0.34 for one application.

6. Both the auto body filler and gypsum-based cement can be applied at temperatures as low as 32°F.

7. Although neither hole filler is completely resistant to chemical agents, the auto body filler is significantly more resistant than the Armor-Plug.

8. The effectiveness and cost of the most feasible BARKS are given in Table 2. Auto body filler (2-part mixture) may be used instead of RTV (one-part adhesive) particularly below 50°F.

9. BARK solutions for armored vehicles are given in Table 3.

10. Two artificial heating methods, a self-regulating heater and a toroid induction heater, can be used to heat steel from below 32°F to 60°F using the 24-volt source on the tank.

11. A methacrylate-soaked fiberglass patch was successfully used to repair a leak on an M60 fuel tank and a leak on an oil pan on a crane at Ft. Knox.

Table 2. BATTLEFIELD ARMOR REPAIR KIT VERIFICATION RESULTS

	Protects From:			Cost/ Repair
	Water	Chemicals	Ballistics	
Phase I - FY84				
1. Polyester Filler with Fiberglass	x	x		\$ 0.29
2. Fiberglass Patch and Bonded Steel Plate	x	x	1 Hit	\$15.00
3. Toggle Bolt Attached Steel Plate/RTV	x	x	1 Hit	
4. Stud-Welded Steel Plate/Filler	x	x	x	
Phase II - FY85				
1. Auto Body Filler, NSN 8010-00-926-2133	x	x		\$ 0.22
2. Concrete	x			\$ 0.34

Table 3. BARK SOLUTIONS

Vehicle	Expedient Repair*	Permanent Repair
M1	Auto Body Filler	Weld Plates Around Periphery
M60	Auto Body Filler	Stud-Weld Patch
M113	Auto Body Filler	Weld Procedures To Be Formulated
BFV	Auto Body Filler (Screen For 1/4" Steel)	As Above For M1 and M113

*Armor-Plug is a viable, but more expensive solution.

ACKNOWLEDGMENT

Dr. Piyush Dutta and David Carbee were very helpful in performing tests at the Army Cold Region Research and Engineering Laboratory. Harry Reeves and his staff performed the explosive tests at BRL. Ray Astor of AMSAA made a number of helpful suggestions. Dr. Stanley Wentworth of the U.S. Army Materials Technology Laboratory reviewed the report and provided useful input.

APPENDIX A - ARMOR-PLUG ANALYSIS - CONSULTANT'S REPORT

TO: David D. Double, Cemcom Research Associates, Inc.
FROM: Randall Bright
DATE: March 27, 1985
RE: Anaylsis of Army "Tank Repair" Cement

Physical Appearance: Gritty, Grey powder with ½" fiber reinforcement

Sieve Analysis:

	Wt%
Fiber	1.0
+40	2.2
-40/+100	27.2
-100/+200	5.3
-200/+325	22.3
-325	42.2
	100.0

Scanning Electron Microscopy and Energy Dispersive X-Ray Spectrometry

The powder sample and fibers were examined under a Scanning Electron Microscope (SEM) and analyzed using an Energy Dispersive X-ray Spectrometer (EDS). Three separate species were identified by SEM/EDS analyses. The first material identified was the fibers. Through EDS analysis these fibers were determined to be A.R. (Alkali Resistant) glass. This glass is easily distinguishable due to the high percentage of zirconia present (see Table I). This glass is also known as zirconia glass. It was developed for use as a reinforcement in a cementitious environment, where high pH levels are present.

TABLE I
Composition of Glasses (Wt. %)

Constituent	Unknown Glass Fiber	"E" Glass	"A" Glass	A. R. Glass Cem-FIL Glass	A. R. Glass ARG Glass
SiO_2	59.4	55.2	72.0	71	60.7
Al_2O_5	----	14.8	2.5	1	----
B_2O_3	*	7.3	.5	----	----
ZrO_2	18.0	----	----	16	21.5
MgO	----	3.3	.9	----	----
CaO	4.7	18.7	9.0	----	----
Na_2Q	17.9	.3	12.5	11	14.5
K_2O	----	.2	1.5	----	.2
Li_2O	*	----	----	1	1.3

*Boron and Lithium are not seen by the EDS Detector.
From K. L. Loewenstein, The Manufacturing Technology of Continuous Glass Fibers, Elsevier, New York, 1983, pg. 34.

The second material identified was a large crystalline form. Particles of this species ranged from 50 μm to 5 mm. A typical micrograph is shown in Figure 2. EDS analysis found this material to be composed of 100% SiO_2. It is most likely that this material is sand or ground quartz.

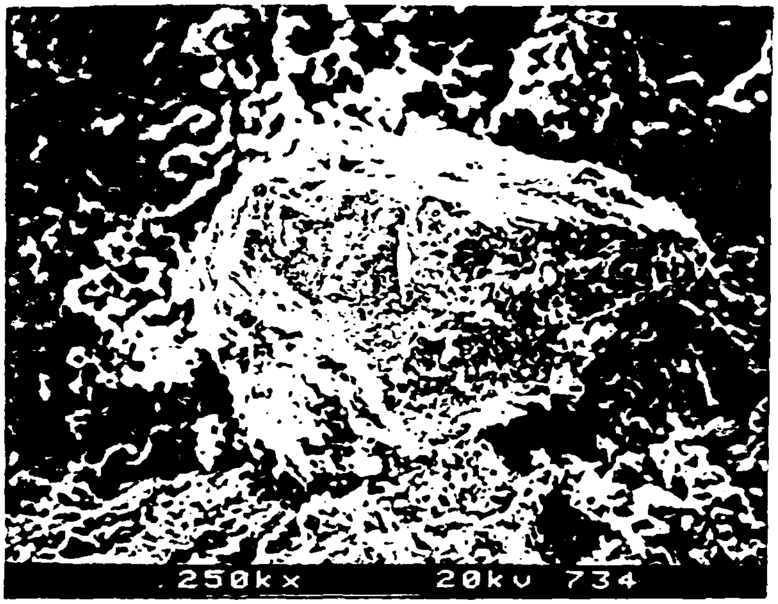

Figure 2. SEM Micrograph of Large Crystalline Form.

The third material identified was a smaller crystalline form. Particle size range of this material was less than 100 μm. The crystals were found to be needle-like in shape. A typical SEM micrograph is shown in Figure 3. EDS analysis showed these crystals to be composed of calcium and sulfur (see Figure 4). From the proportions of the two it is very likely that this material is $CaSO_4$, probably present as the hemihydrate; $CaSO_4 \cdot \frac{1}{2} 2H_2O$ (gypsum or plaster).

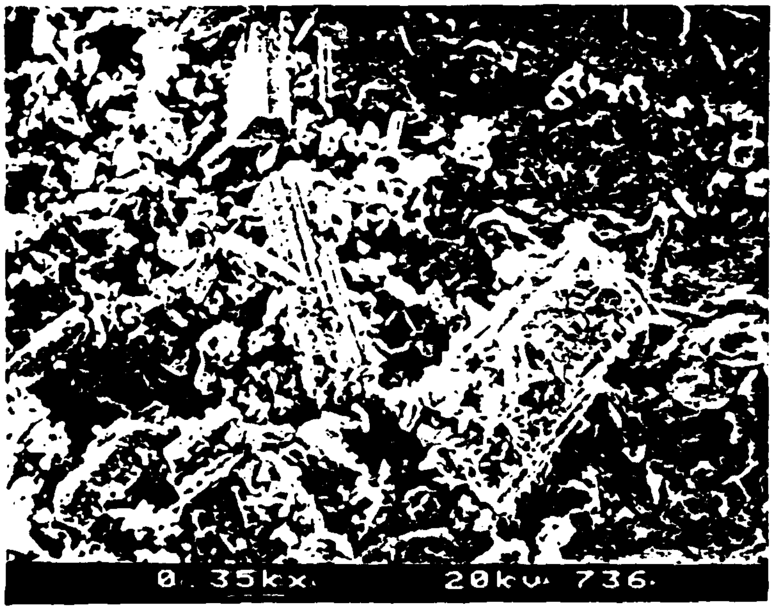

Figure 3. SEM of Smaller Crystalline Form.

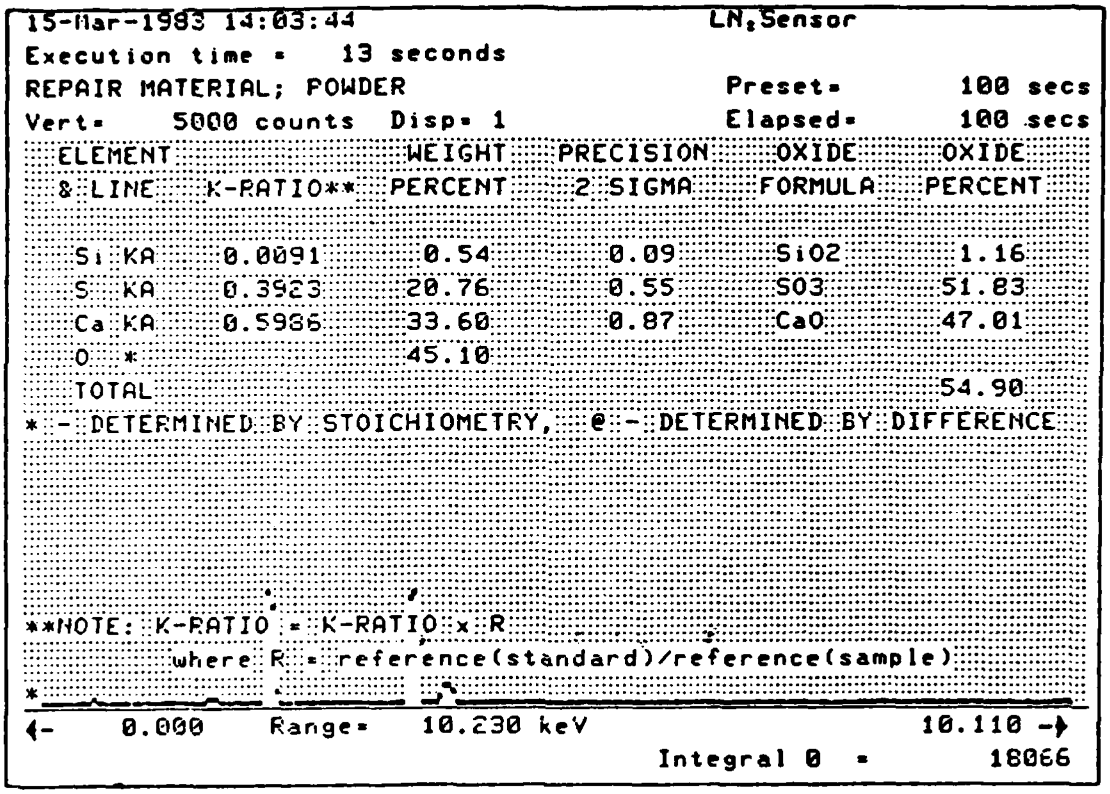

Figure 4. EDS Analysis of Smaller Crystalline Form.

Discussion

From the sieve and microscopic analyses, a compositional formulation can be estimated:

	Wt%
1/2" A.R. glass fibers	1
40/200 sand	30-39
gypsum	60-69

In a gypsum matrix, the pH is not very high, and the use of A. R. glass isn't required. E glass fibers (borasilicate) would be sufficient in this pH range (pH 9-10). At 1% w/w fiber loading, not very much reinforcement is achieved, although the impact resistance should be increased. The impact strength of a glass reinforced gypsum plaster is approximately twice that of a glass reinforced cement have the same fiber loading. This is due to the weaker fiber-matrix bonding, which allows more energy absorption by fiber pull out. Still, a 1% fiber loading is very low, especially in this case, where the fibers are randomly alinged.

The choice of gypsum as a matrix for this application also appears to be unwise. Hydrated gypsum, $CaSO_4 \cdot 2H_2O$, is slightly water soluble, and a 50% loss in strength is typically observed when a gypsum composite is water saturated.

APPENDIX B - HOLE FILLER

WARNING: Keep filler away from sun or heat. Avoid prolonged breathing of vapor. HARMFUL IF INGESTED. If ingested do not induce vomiting. Consult physician. Irritant to skin or eyes. Flush with plenty of water in case of contact.

GENERAL INFORMATION

Auto body filler (one-quart can with creme hardener in tube) NSN 8010-00-926-2133 is normally used to repair damaged military and civilian auto bodies. When a golf-ball-size lump of filler is thoroughly mixed with 2 inches of creme hardener, the time to harden will be determined by the temperature.

Temperature	Hardening Time
Above 90°F (32°C)	Less than 5 minutes
Between 50°F and 90°F (10°C and 32°C)	5 to 7 minutes
Between 32°F and 49°F (0 and 10°C)	More than 7 minutes
Below 32°F (0°C)	*Will not harden

*Apply external heat, such as the exhaust from another vehicle, to increase the temperature.

NOTE: Use less creme hardener to increase hardening time. Use more creme hardener to decrease hardening time.

Personnel/Time Required

- One soldier
- 15 minutes.

Materials/Tools

- Auto body filler (1-quart can), NSN 8010-00-926-2133
- Creme hardener (1- or 4-ounce tube)
- Eye protection
- Wire brush (or substitute)
- Sledge hammer (or substitute)
- Clean rag (or substitute)
- Putty knife (or substitute)
- Tape (or substitute).

Procedural Steps

1. Clean dirt, grease, and/or oxide from edge of hole with wire brush (or substitute). Wear eye protection.

2. If hole has protrusion or lip, hammer as flat as possible or remove. Wear eye protection.

3. Wipe edge of hole clean and dry with clean, dry rag (or substitute). Do not use oil-soaked rag.

4. For holes larger than 2 inches in diameter, use tape (or substitute) to close back of hole, if possible.

5. Place golf-ball-size lump of filler (from can) on clean, dry, hard, smooth surface.

6. Thoroughly mix in 1 inch of creme hardener (from tube) with putty knife (or substitute). Mix thoroughly and quickly (see General Information for hardening time).

7. Spread thin coat of mixed filler on edges of hole with putty knife (or substitute), assuring good bond, then fill entire hole to original contour of vehicle.

8. Mix additional filler if required. Do not return mixed filler to can.

9. Do not disturb patch during 15-minute curing time.

APPENDIX C - ARMOR-PLUG™

WARNING: Will cause eye irritation; may cause skin irritation if exposure is prolonged. Flush or wash with plenty of water in case of contact.

GENERAL INFORMATION

Armor-Plug is a rapid setting material that can be handled the same as concrete. At temperatures between 50°F and 90°F (10°C and 32°C) Armor-Plug will harden within 5 to 7 minutes after being mixed with water. At temperatures above 90°F (32°C) working time will be less. Between 32°F and 50°F (0°C and 10°C) working time will be longer. Below 32°F (0°C) the material will not harden.

Personnel/Time Required

- One soldier
- 15 minutes.

Materials/Tools

- Sledge hammer
- Armor-Plug kit including Armor-Plug and cup
- Stainless steel wire brush
- Clean rags
- Wooden applicator
- Duct tape.

Procedural Steps

1. Use stainless steel wire brush to remove dirt, grease, or oxide from hole. Wear eye protection.

2. If hole has protrusion or lip, hammer flat as possible or remove. Wear eye protection.

3. Wipe interior of hole clean with dry rag.

4. For large holes greater than 2 inches in diameter, use aluminum tape or duct tape to close back of hole if possible.

5. Open outer bag and remove plastic bag. Remove cup from plastic bag. Pour one full cup of water into plastic bag with dry material.

6. Squeeze air from bag, then seal bag completely.

7. While holding the bag in both hands, knead the mixture for 2 to 3 minutes or until completely free of lumps. Mix may harden in less than 5 minutes.

8. Turn bag inside out and press material into hole or apply with applicator. Use applicator to scrape away excess material.

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BATTLEFIELD ARMOR REPAIR KITS - PART 2
Alan J. Goldman and Dennis W. Gosselin

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Key Words
Armor
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Polyester resins

A readily available, inexpensive auto body filler is useable for battlefield armor repair at temperatures between 32°F and 95°F. The filler contains 50% polyester resin and 50% magnesium silicate. It has a federal stock number and is easily procured through GSA. A feasible but more expensive hole filler is a reinforced gypsum cement commercially known as Armor-Plug. It has the advantage of being odorless. Both products have a shelf-life of two years. Armor-Plug costs $0.34 for one application compared with $0.22 for the auto body filler. In explosive tests performed by troops from the Fort Knox Armor School and the Aberdeen Ordnance Center and School, both of these hole fillers performed virtually the same.

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